A Catchment Scale Irrigation Model For Sugarcane

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Abstract

In South Africa, the demand for water exceeds available supplies in many catchments. As a result, farmers are facing increasing pressure to use water more effectively, to justify existing water requirements and to budget and plan with growing uncertainty regarding water availability. Therefore, a tool to manage and assess catchment water supply and demand interactions and the associated impacts on the profitability of irrigated sugarcane would be of great value. In this document the development of such a catchment scale irrigation systems modelling tool is described. The model has application for testing and assessing various operating, water allocation, water management and water resources development strategies. The tool is also designed to predict the expected performance of different types of irrigation system hardware.

Keywords: *Irrigation Systems, Water Management, Modelling, Hydrology, Water Resources, Sugarcane.*

1 Introduction

In South Africa, the demand for water exceeds available supplies in many catchments. Since a substantial amount of water is assigned to irrigated agriculture (Ascough and Kiker, 2002), farmers are facing increasing pressure to use water more effectively and to justify existing water use. In order to justify existing water requirements and to budget and plan in the context of growing uncertainty regarding water availability, a tool to assist in the assessment and management of catchment water supply and demand interactions, and the associated impacts on the profitability of irrigated sugarcane, is needed.

While there have been many useful model developments for sugarcane and water resources management, none of these provide all the necessary decision support information in an integrated fashion. Therefore, the development of a catchment scale irrigation system model, as described in this document, was initiated.

2 Methodology

In order to distil the concepts best suited for the development of the tool required, in-field evaluations of irrigation systems were undertaken with a mobile irrigation laboratory (MIL) and a review of appropriate literature and models was conducted. Ascough and Lecler (2004) reported on an analysis of the results from the MIL evaluations and highlighted, amongst others, the importance of water supply and demand interactions on the performance of irrigation and water management systems. In the review of models and literature, the following models were appraised: SWB (Campbell and Diaz, 1988). CANEGRO (Inman-Bamber, 1991), *ACRU* (Schulze, 1995), APSIM (McCown *et al.*, 1996), CANESIM (Singels *et al.*, 1998) and *ZIMsched* 2.0 (Lecler, 2003). The FAO Irrigation and Drainage Paper No. 56 (FAO 56, Allen *et al.*, 1998) was also reviewed as it is fundamental to the water budget used in *ZIMsched* 2.0 and SWB. A conclusion of the review process was that despite their respective strengths, none of these models and associated algorithms incorporated all the desired system processes, as outlined below, in an integrated fashion.

3 Model description

The *ACRU* model is a catchment scale agrohydrological model capable of simulating many different water supply or availability scenarios (Lecler *et al.*, 1995). Consequently, the *ACRU* model was used to form the water supply link with a smaller sub-model, ACRU*Cane*, developed to simulate the water budget of an irrigated field of sugarcane and the associated sucrose yields when irrigated with with different types of irrigation systems.

The water budget in ACRU*Cane* is based primarily on a unique integration and refinement of robust algorithms from FAO 56 (Allen *et al.,* 1998) and the *ACRU* model (Schulze, 1995). A brief description of the fundamental aspects of the water budget are highlighted below:

Wetting events occur as a result of either rainfall or irrigation, both of which can potentially generate runoff. Runoff from the irrigated area is simulated using an equation developed by the Soil Conservation Service (Agriculture, 1985) and adapted for use in South Africa by Schmidt and Schulze (1987) and Schulze *et al.*, (1995).

$$Q = (PI - cS)^2/(PI + S(1\text{-}c)) \qquad (1)$$

where

Q	=	surface runoff depth (mm),
PI	=	daily wetting amount (mm), i.e. rainfall and/or irrigation
c	=	coefficient of initial abstraction, and
S	=	potential maximum water retention of the soil, taken as the soil water deficit below porosity, prior to a wetting event (mm).

Rainfall and/or irrigation that does not generate runoff is assumed to infiltrate into the soil immediately after the wetting event has occurred. Rates of infiltration are not simulated in *ACRUCane*. Once in the soil profile, water leaves the soil either through evapotranspiration or deep percolation.

Evapotranspiration from the cropped surface is determined using the dual crop coefficient methodology described by Allen *et al* (1998).:

$$ET_c = (K_{cb} + K_e).ET_0 \qquad (2)$$

where

ET_c	=	evaporation from a cropped surface (mm),
K_{cb}	=	basal crop coefficient,
K_e	=	coefficient controlling evaporation from the soil, and
ET_0	=	reverence grass evaporation (mm)

Using dual crop coefficients allows the separation of evaporation from a cropped surface into two processes, namely, transpiration (E_t in mm) and evaporation from the soil (E_s in mm). Treating these two processes separately is important because prior to the development of significant canopy cover, water losses are dominated by evaporation from the soil surface. Accurate estimation of this water loss is important, as it can be highly variable depending on the wetting fraction and wetting frequency of the soil (Lecler, 2003).

If, at the end of the day, the soil moisture content of the root zone (the portion of soil occupied by the roots) is above the drained upper limit of the soil, then drainage of the profile is initiated. The fraction of moisture above the drained upper limit that leaves the soil profile is dependent on the soil textural class. Default values are used based on the soil texture, however, default values can be overridden by a user specified value.

To aid in simulating the water budget, phenological processes such as root growth and canopy development are modelled. Root growth is simulated using a methodology described by Lecler (2003) and accounts for the crop's increasing access to soil moisture during the course of the growing season. Canopy development is simulated using a model described by Singels and Donaldson (2000) and is used to account for the effects of light interception/soil shading, such as evaporation of water from the soil and increased crop water usage.

Different types of irrigation system hardware are accounted for in several ways in ACRU*Cane*. The irrigation system type, e.g. 'drip' irrigation, is associated with system specific attributes such as the fraction of soil wetted by irrigation, and whether or not interception of irrigation water applications occurs. Included in the required input parameter set is an irrigation uniformity index such as the Distribution Uniformity, DU, to enable the simulation of non-uniform irrigation water applications which occur in practice. This is achieved using multiple water budgets and assuming a normal distribution of irrigation depths as described by Lecler (2003) and Ascough and Lecler (2004a). The impacts associated with water management are represented through the simulation of a wide range of irrigation scheduling options.

To estimate associated yields of sucrose, an algorithm developed by Doorenbos and Kassam (1979) and modified by De Jager (1994), is used in ACRU*Cane*.

$$Y_a/Y_p = \Sigma(1 - K_{yi}(1 - E_t/E_{tm})) \qquad (3)$$

Where Y_a = actual yield ($t.ha^{-1}$),
Y_p = potential yield ($t.ha^{-1}$),
K_{yi} = yield response factor for the ith growth period,
E_t = simulated actual transpiration (mm), and
E_{tm} = simulated maximum transpiration, i.e. with no soil water stress (mm).

Thus with an estimate of the potential sucrose yield it is possible to determine the actual yield by accounting for the impacts of water stress via the ratio of actual to potential transpiration at different times in the growth cycle. The potential sucrose yield is obtained using a modified version of the relationship derived by Thompson (1976) as described by Lecler (2003).

A second, radiation based, biomass accumulation yield model developed for CANEGRO has also been included in ACRU*Cane*. This model estimates, *inter alia*, the sucrose and fibre content of the stalk. A comprehensive description of this yield model is provided by Singels and Bezuidenhout (2002). To estimate sugarcane yield, an empirical relationship developed by Thompson (1976), between sugarcane yield and crop evapotranspiration is used.

A variety of water supply options can be simulated by ACRU*Cane* through the ACRU model. These options are shown in Figure 1. The user can thus quantify the impact of different water supply options and constraints on the water budget and ultimately the yield of an irrigated sugarcane crop.

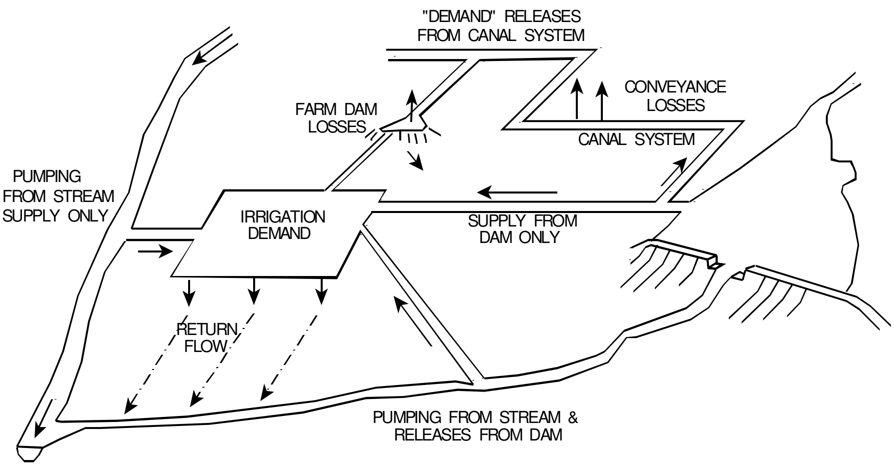

Figure 1. Schematic Diagram of supply options available in ACRU (Schulze, 1995)

4 Results

Verification of the yield estimation algorithms in ACRU*Cane* was conducted using trial data from both La Mercy in KwaZulu-Natal and the Lowveld of Zimbabwe. At La Mercy, five different treatments were applied to trial plots, ranging from full irrigation to rainfed conditions, over a four year period that included one plant crop and three ratoons. Estimates of sugarcane, ERC and sucrose yield were simulated and compared against observed values of sugarcane and sucrose yield for the ratoon crops. The following Root Mean Square Errors (RMSE) values were obtained in estimating the yield:

Table 1. RMSE of simulated yield estimated at La Mercy

Yield Estimate	RMSE	MEAN (t/ha)
Sugarcane	16.7	121.1
ERC	2.4	17.6
Sucrose	2.4	17.6

These errors, when expressed as percentages of the mean observed yield, are all indicative of accurate yield prediction. The RMSE obtained when estimating sucrose compares favorably with the value of 2.6 t/ha obtained by Singels and Bezuidenhout (2002). Figure 2 shows a scatter plot of simulated and observed sugarcane yields obtained using the Thompson model. A "best fit" line applied to the data yielded a gradient of 0.8499 and a y-intercept of 8.67, indicative of simulated values following a very similar trend to observed values.

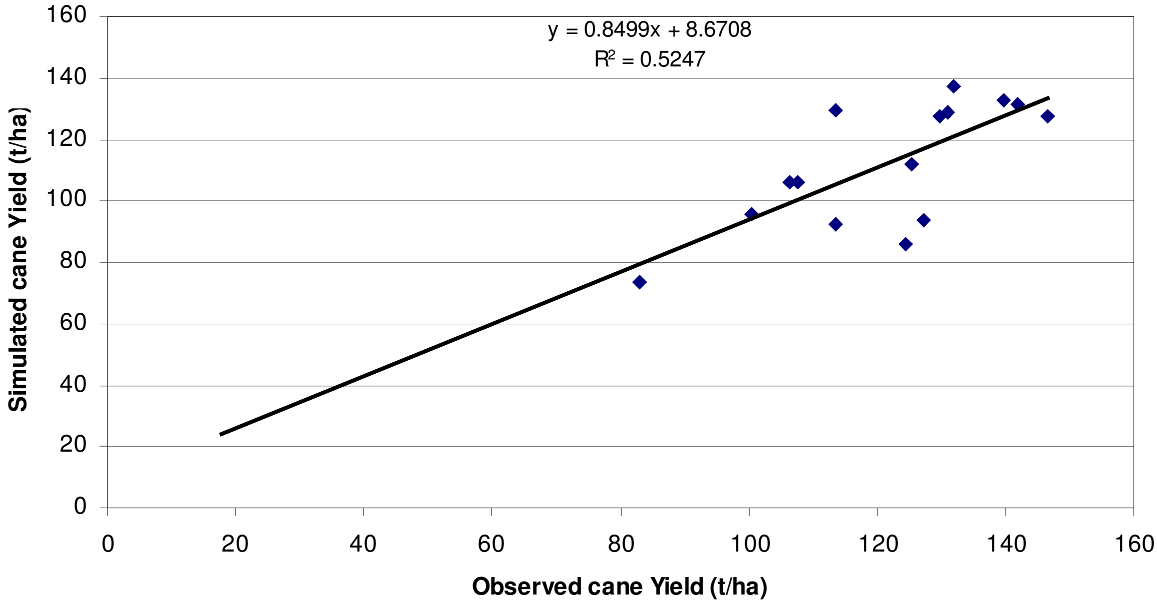

Figure 2. Simulated vs observed sugarcane yield (t/ha) at La Mercy

In Zimbabwe, an irrigation trial was conducted from 1966 to 1972 using six different irrigation treatments. ERC and sugarcane yields were estimated and compared against observed data. The trial plots had previously never been planted to sugarcane or any other form of commercial agriculture, and as a result, observed yields were exceptionally high. Since ACRU*Cane* does not account for soil quality, estimated yields tended to be lower than those observed. However, when comparing relative yields, i.e.: yields expressed as a fraction of the maximum, the model was shown to perform well as shown in Figure 3.

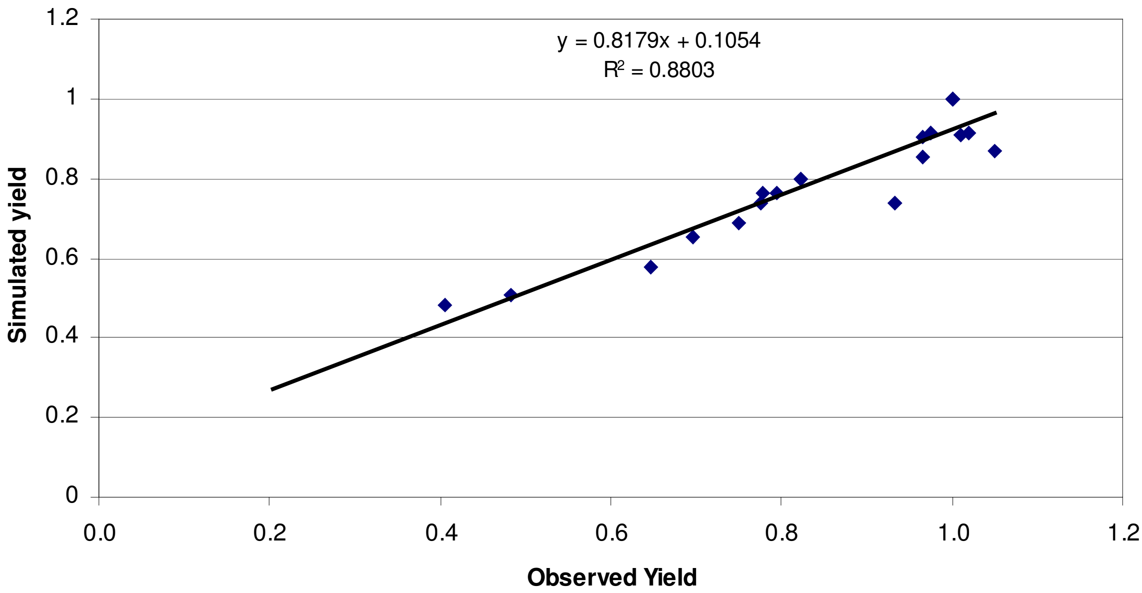

Figure 3. Simulated and observed relative ERC yields in Zimbabwe

Table 2. RMSE of simulated yield in Zimbabwe

Yield Estimate	RMSE	MEAN (t/ha)
Sugarcane	0.064	0.84
ERC	0.081	0.83

As with the results from La Mercy, when these results are expressed as a fraction of the mean they indicate that the model has performed well. For instance, relative sugarcane yield was predicted with a 7.6% error when compared to the mean. The RMSE of 0.081 obtained when estimating relative ERC yield compares favorably with that of 0.056 obtained by Lecler (2003).

5 Conclusion

A core objective of this project was to integrate simulated crop water requirements, sucrose yields and the availability of water from a catchment, i.e. from a dam or directly from a river. Furthermore, these simulations needed to be representative of various water management and irrigation hardware systems. These objectives have been achieved and the results of the verification study show that the model to have performed adequately. Actual yields were captured accurately on most occasions. In instances where actual yields were not simulated well, relative differences in yield resulting from different irrigation treatments were represented well by the model. ACRU*Cane* has the potential to provide management information to a wide range of users. It should enable the expected performance of different types of irrigation and water management systems to be investigated. Furthermore, all of these can be assessed in relation to risks associated with available water supplies, water allocations and allocation systems providing information needed to assess the potential profitability of various alternatives. In terms of water resource assessments ACRU*Cane* could be used to determine impacts of a given area of irrigated sugarcane on water availability or *vice-versa*, for a range of irrigation systems and water management scenarios.

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